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STRUCTURED BACKSIDE GLASS FOR IMPROVED EFFICIENCY IN SOLAR MODULES

A SIMULATION STUDY

L. Stevens[1], B. Bläsi[1], C. Horch[2], S. Ihlow[2], M. Mittag[1]
[1] Fraunhofer ISE, Heidenhofstraße 2, 79110 Freiburg, Germany
[2] GMB Glasmanufaktur Brandenburg GmbH, Spremberger Straße 4, 03130 Tschernitz, Germany
laura.stevens@ise.fraunhofer.de

ABSTRACT: Increasing the efficiency of a photovoltaic module is still an ongoing research topic. To achieve this, we focus on the light management in the module. We perform a simulation study using Raytracing and a bottom-up multi-physic loss channel cell-to-module (CTM) analysis to study the influence of structured backside glass for bifacial glass-glass modules on the performance. The study was done to determine the module power output based on an AM1.5g spectrum including different incoming angles as an estimation of the yearly energy yield. These results are compared to modules with conventional white polymer backsheet or planar backside glass. It was found that a structured backside glass improves the light coupling into the module and internal light management through enhanced internal reflection. We study a cone structure and perform a variation of the cone angle to find an optimum in the reflection gain. We show that the highest reflection gain of 1.43% compared to a full absorbing backside for a cone structure with an angle of 35° is achievable. The theoretical cone structure was then adapted to realistic production conditions by implementing roundings. For structures with 20% rounding the reflection gain was lowered to 1.39%. The reflection gain of a white polymer backsheet was 1.47% and, thus, higher compared to the structured glass, However, compared to a planar glass with 0.11% the reflection gain of the structured glass is much higher and allows for improved bifacial modules. We also study the influence of the backside irradiance and show that for modules with structured glass a gain is obtained in comparison to modules with a white polymer backsheet. Hence, glass with optimized structures can replace backsheets without compromising the internal reflection gains.

Keywords: structured module glass, light guiding, raytracing, CTM analysis

1 INTRODUCTION

A good light management in solar modules is important to maximize the energy conversion efficiency. The front glass is typically coated with an antireflection coating (ARC) to increase the transmission of the light. Advantages of macroscopic structures in terms of yield have already been confirmed [1] for front side glasses. The advantages of a front side glass structuring can also be used for a backside glass.

The optimization in this study aims for trapping light in the module and redirecting rear side light to bifacial solar cells in the module. This can increase the module efficiency and is, therefore, relevant for the optimization of solar modules. In solar modules a white backsheet or a planar backside glass are commonly used at the rear side. Modules with a white backsheet can gain from a good scattering of transmitted light [2]. In comparison to that, solar modules with a transparent backside can make use of albedo illumination from the rear. Having a structured backside glass improves the light coupling into the module and internal light management through light steering and, thus, enhance internal reflection. In Figure 1 a schematic cross section view of the three backside types with possible light paths are shown.

The aim of this study is to design and evaluate structured backside glasses for glass-glass-modules. To this end, a simulation study was performed to find optimal structure parameters to increase reflection gains (for front side illumination) compared to a fully absorbing backside. Also, the influence on the module power with different backside illumination for a module with a white backsheet in comparison to a module with a structured backside glass was investigated.

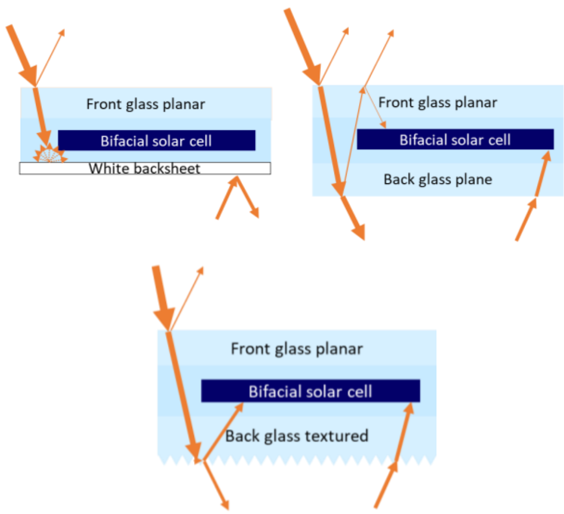

Figure 1: Cross-section views of the modules with different backsides and some possible light paths from the front and the backside: white backsheet (left), planar backside glass (middle), structured backside glass (right).

2 METHOD

The starting point for the simulation of the solar modules is the software tool SmartCalc.Module [3–5] , implementing a bottom-up multi-physics loss channel analysis of PV modules developed at Fraunhofer ISE. It allows modules to be simulated optically, electrically, and thermally. The optics of a planar encapsulation material can be described by the spectral refractive index and planar interface reflectance and transmittance. For structured interfaces, the optical models are extended to describe feature sizes that allow to use geometric optics. Therefore, a CAD model of the structure was used in ray tracing simulations. The ray tracing framework Raytrace3D [6] developed at Fraunhofer ISE was used to investigate three-dimensional surfaces. The raytracing results along with 1000 W/m² direct normal irradiance of a AM1.5g light are then used as an input for the SmartCalc.Module analysis. The incoming light angles are varied so that the course of the sun around a year is simulated. A schematic workflow is shown in Figure 2. The single steps are described in more detail in the following.

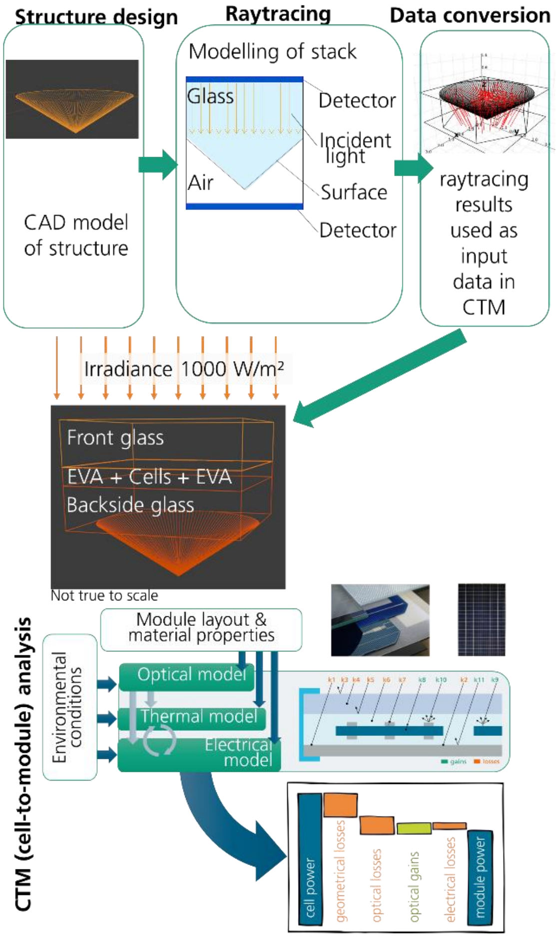

Figure 2: Schematic workflow of the simulation process to calculate the reflection gain for a structured backside glass, partly adapted from [7,8].

2.1 Raytracing analysis

The aim of the raytracing analysis is to generate a reflection or transmission distribution of incident light on a structured glass surface. The light can be emitted both inside and outside the glass, so that in the first case the internal and in the second case the external reflection at the glass can be considered.

Raytrace3D [6] includes a library of ray tracing functions written in C, which can be controlled and used through Python scripts. Various files containing the model parameters are used as input, as well as a simulation script that bundles all the information about the system to be simulated. For example, this script defines the optical properties of the materials in the model, the triangulated glass structure (from a 3D model), the shape and size of the light source, and the number and properties of the beams. Additional scripts were added, which control the running of multiple simulations with different parameters and transfer the result into a format that can be further used. Thus, multiple angles of incidence and wavelengths as well as structural variations can be run. For this simulation study zenith angles θ for 0°,30°,60°,90° and azimuth angle ϕ for angles from 180° to 147.5° in 2.5° steps have been simulated. The simulation results from raytrace3D will be used as input for the cell-to-module (CTM) analysis.

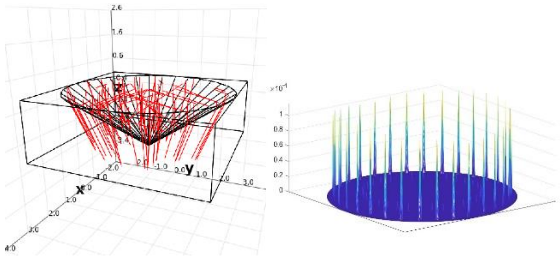

Figure 3: Ray tracing for a segmented cone at perpendicular incidence: visualization of the model (left) and the resulting reflectance distribution as polar plot (zenith angle radial, azimuth angle circular) (right).

2.2 CTM (cell-to-module) analysis

Cell-to-module loss analysis involves the consideration of various loss mechanisms that result from the encapsulation of a solar cell into a solar module. In Figure 4 the eleven different loss (orange) and gain (green) mechanisms [3] in a solar module are schematically shown.

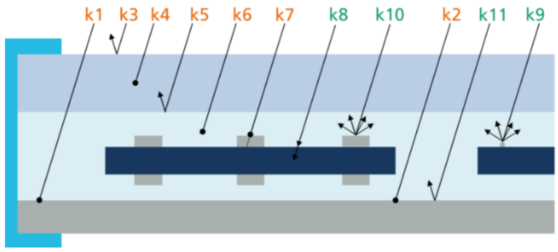

Figure 4: Schematic module cross-section illustrating the loss and gain mechanisms in the solar module.

Optical losses are primarily due to reflection from the module surface, usually a glass surface on the front of the module (k3 in Figure 4). In addition, light is absorbed in the front side encapsulation materials and is, therefore, not available to generate electricity, but only contributes to the heating of the module (k4 and k6 in Figure 4). To determine these losses, the spectral reflectance and transmittance of the glass (and encapsulation material) is needed. For a more detailed consideration, and in particular for structured surfaces, the angular distribution of the light is also relevant instead of the hemispherical values of the reflection and transmission. The bidirectional reflection or transmission distribution function (BRDF, BTDF) is then required, which describes the intensity distribution of the reflected and transmitted light in each spatial direction for a given angle of incidence. This then also provides a direct estimate of the glare effect of a surface, which is relevant for modules near airports or on building facades, for example.

An optical gain can occur in the solar module compared to the solar cell due to internal optical coupling, for example, when light impinging on "inactive" module surface, i.e. surface not occupied by cells, is reflected at the back of the module and then impinges on the front or back (for bifacial cells) of the cell (k11 in Figure 4). To calculate this coupling gain, the BRDF of the backside interface is needed. Another additional power gain occurs in bifacial modules due to light incident on the cell through the module back surface. For this, the same material information like the BRDF and material properties are needed for the module back surface as for the front surface. The results from the ray tracing study provide the relevant data for the investigated structures here.

In addition to the irradiation in the wavelength range relevant for the cell, the heat input into the module is also considered. This and the thermal properties of the module materials influence the operating temperature of the solar module under real weather conditions compared to temperature-controlled power measurement or simulation under standard test conditions (STC).

The I-V characteristic of the cell is then used to determine the power output of the module under given irradiance, temperature and wind conditions. Thus, a power simulation can be performed for various operating conditions, so that a complete annual cycle can also be mapped.

The results of the CTM analysis are then used to calculate the diffuse reflection gain. A detailed description of the method is published here [9].

3 RESULTS

We performed a simulation study of a cone structure where we changed the slope angle of the cone from 5° to 55°. This structure was then integrated into the module simulation of SmartCalc. A module with 60 cells with 4 mm cell spacing was selected for this purpose. The structured glass was selected for the rear side instead of a backsheet. We investigated the diffused reflection gain of the different structures in comparison to a fully absorbing backside. In Figure 5 the results of this simulation study are shown.

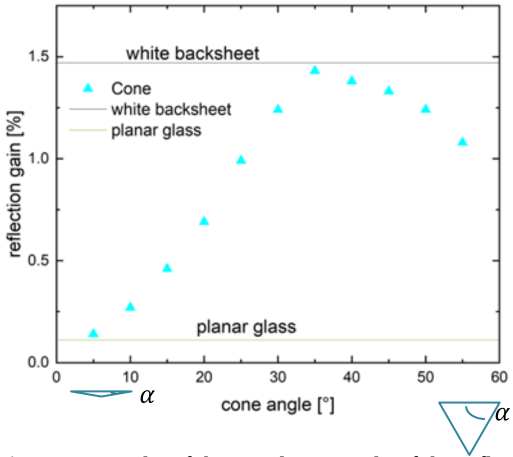

Figure 5: Results of the simulation study of the reflection gain for variating cone angle.

It is visible that the reflection gain increases with increasing slope angle of the cone until it reaches its optimum in reflection gain of 1.43% for a cone angle of 35°. The reflection gain of a white backsheet is included for comparison. The white backsheet has a very good light scattering but does not allow any yields from the back due to back illumination of the solar module.

3.1 Adaption: Roundings

The cone structure investigated before is quite theoretical. In a rolled glass production line there would be a rounding at the cone tip. Therefore, the structure was adapted to realistic production conditions by implementing roundings of 10 % or 20 % of the cone base radius. A visualization is presented in Figure 6 in the top as a sketch and below as an 3D image.

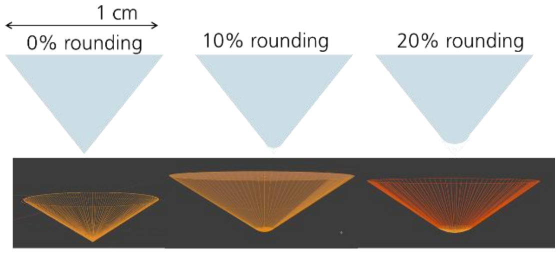

Figure 6: A sketch of the different rounded cones (top) and 3D images of the adapted cone structures with the different rounding (bottom).

The simulation process was again used for the adapted structures. The simulation results presented in Figure 7 show that by implementing roundings the reflection gains decrease slightly. The cone with 10% rounding has a reflection gain of 1.41%, the cone with 20% rounding has a reflection gain of 1.39%. The reflection gain of the white polymer backsheet is 1.47% and, thus, higher compared to a planar glass with 0.11% as the reflection gain of the structures is significantly higher.

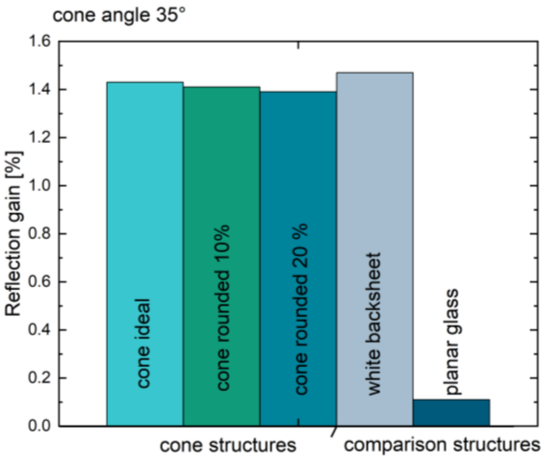

Figure 7: Reflection gain comparison for the ideal cone structure and for cones with different roundings compared to a white backsheet and a planar glass.

3.2 Adaption: Backside irradiance

The advantage of a module using backside glass is that also light from the backside can enter the module and thereby increase the power.

In Figure 8 the results of a SmartCalc.Module analysis of the module power for a module with a white backsheet and for a module with the structured glass is presented. The front side irradiance is 1000 W/m² and the backside irradiance is varied from 100 to 200 W/m².

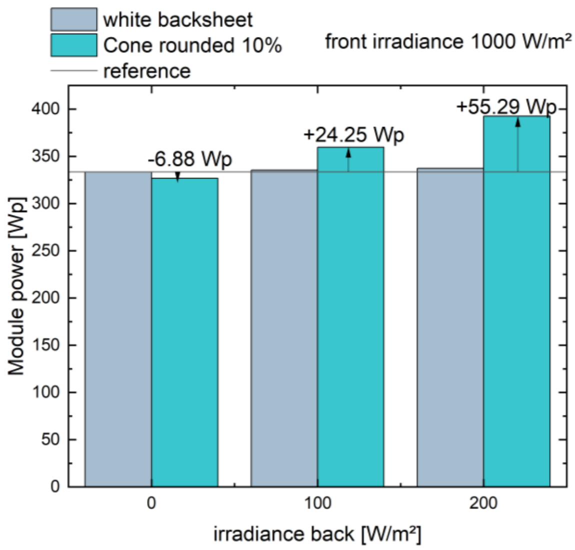

Figure 8: Module power for modules with either white backsheet or a structured glass with variating backside irradiance. The front irradiance is fixed at 1000 W/m².

It is visible that with increasing backside illumination the module with the backside glass has an advantage in the module power and shows a plus of 55.29 Wp for 200W/m² backside irradiance.

3 CONCLUSION

We used a combination of a raytracing and cell-to-module analysis to evaluate the reflection gain of a cone structure applied on the outside of a glass used on the module rear side. We could find an optimum in the reflection gain with 1.43% for a cone with a slope angle of 35°. The theoretical structure was adapted to realistic production conditions by implementing rounding at the cone tip. These roundings decrease the reflection gain down to 1.39% for a rounding of 20% of the cone radius. Compared to a standard white backsheet, which has a reflection gain of 1.47%, the cone structure features a slightly lower gain. However, the glass-glass module has the advantage of using albedo light from the backside. Our simulations could show that there is a significant module power increase with backside module illumination.

We could show that the structured backside glass helps to increase the module power output compared to a planar glass and can replace backsheets without compromising internal reflection gains.

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